Amendments to the Specification

Please replace paragraph [0004] with the following amended paragraph:

[0004] Qualitatively, a superposition of basis states means that the qubit can be in both basis states $|0\rangle$ ~~and ($|1\rangle$) at~~ and $|1\rangle$ at the same time. Mathematically a superposition of basis states means that the overall state of the qubit, which is denoted $|\Psi\rangle$, has the form

$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

where α and β are probability amplitudes. The terms α and β each have real and imaginary components. Typically, when the state of a qubit is measured (*e.g.*, read out), the quantum nature of the qubit is temporarily lost and the superposition of basis states collapses to either the $|0\rangle$ basis state or the $|1\rangle$ basis state, thus regaining its similarity to a conventional bit. The actual state of the qubit after it has collapsed depends on the probability amplitudes α and β immediately prior to the readout operation.

Please replace paragraph [0034] with the following amended paragraph:

[0034] Barone *et al.* uses radiation free couplings to perform limited forms of quantum logic gates. The operations are defined as static interactions between the first two levels and the third higher energy level. The Barone *et al.* system includes a normal metal (*i.e.*, non-superconducting) ring interrupted by a plurality of insulating layers threaded by a static magnetic flux. In particular, Barone *et al.* uses a transverse electric field applied to a normal metal ring that is interrupted by a plurality of insulating layers in order to generate a discrete set of gates. Barone *et al.* do not use electro-magnetic radiation to effect qubit operations. While Barone *et al.* does make use of the third energy level, they do not create a set of gates that have a ~~continuos~~ continuous angle of rotation, θ, with respect to the quantum state of the qubit.

Please replace paragraph [0042] with the following amended paragraph:

[0042] Other embodiments of the present invention include a qubit comprising a molecule having a first and a second ground state, the ground states corresponding to energy levels in a double well energy potential having an associated tunneling amplitude. A Rabi oscillation between the first basis state and second basis state of the molecule is induced. The tunneling amplitude, expressed in frequency units, is less than the frequency of the Rabi oscillation. In some of these embodiments, the tunneling amplitude, expressed in frequency units, is approximately equal to or less than the arithmetic inverse of a decoherence time associated with the qubit. In some of these embodiments, the molecule is comprised of a chemical entity (e.g., compound) comprising an element that is in a reduced state (e.g., the element is hydrogenated with two or more hydrogen atoms). In some of these embodiments, the molecule is of the form XY_3 where X is an atom such as arsenic, or phosphorus, and wherein each Y is the same or different and is independently selected from the group consisting of hydrogen, deuterium, and tritium. In some of these embodiments, the chemical entity is ~~asine~~ arsine (AsH_3) or phosphine (PH_3).

Please replace paragraph [0058] with the following amended paragraph:

[0058] A fourth aspect of the invention describes an $R_X(\theta)$ operation that can be efficiently performed on systems for a ~~continuos~~ continuous range of rotation angles θ. In this fourth aspect of the invention, detuning of pulse or variation of amplitudes of in-pulse sequences is used to effect an $R_X(\theta)$ that is a proper quantum NOT operation. This aspect of the invention is described, for example, in Sections 5.1 and 5.2, below.

Please replace paragraph [0062] with the following amended paragraph:

[0062] In this aspect of the invention, an alternating signal is applied to a system described by potential energy diagram 190 (Fig. 1B). These transitions can be treated as an implementation of $R_X(\theta)$ and hence can be used to realize universal quantum computing. More specifically, when an alternating signal having a frequency that depends on the energy difference between energy levels (states) 100-2 and 100-1 is applied to the system, the system state will undergo Rabi oscillations between energy levels 100-0 and 100-1. Here,

the energy difference between energy levels 100-2 and 100-1 is the same as the energy difference between energy levels 100-2 and 100-0 because they are degenerate (*i.e.*, they have the same energy). The frequencies ω_{02} and ω_{12} depend on the respective energy level difference as $\omega_{02} = (E_{100\text{-}2} - E_{100\text{-}0})$ and $\omega_{12} = (E_{100\text{-}2} - E_{100\text{-}1})$, where $\hbar = 1$ throughout the present invention, ~~a~~ as one of skill in the art will realize that $\hbar$ can be multiplied onto any angular frequency variable in order to get the corresponding energy value with correct unit conversion. The notation $E_{100\text{-}X}$ refers to the energy of energy level 100-X.

Please replace paragraph [0068] with the following amended paragraph:

[0068] Fig. 1D illustrates the evolution of the system as a probability of the occupation of the system states with respect to the rotation angle or period of evolution. The detuning level is illustrated as $\delta = 0.5*|u|$, where $|u|$ represents the ~~affect~~ effect of the applied alternating signal on the system. The only difference between Figs. 1C and 1D ~~are~~ is that the term $\delta \neq 0$ has been introduced. The system now has two rotation angles ~~where~~ when the population in the non-information state (state 100-2 from Figure 1B) is zero. Starting from an initial condition that the system is in the state $|\Psi\rangle = |0\rangle$, after an evolution r_1, which corresponds to $2\pi/3$ in Fig. 1D, the system is in a superposition of the states 100-0 and 100-1. This superposition of states is $|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle$, where $\alpha \approx 0.75$ and $\beta \approx 0.25$. After a complete period, the system returns to the initial state $|0\rangle$.

Please replace paragraph [0069] with the following amended paragraph:

[0069] Fig. 1E illustrates the same situation as Figs. 1C and 1D, with the exception that the detuning is $\delta = \sqrt{\frac{8}{3}}|u|$, where $|u|$ characterizes the effect of the applied alternating signal. The behavior illustrated in Fig. 1E shows that, for this value of detuning, the system implements a quantum NOT operation. Once again the initial state of the system is $|\Psi\rangle = |0\rangle$, and after an evolution r_1, the energy level 100-2 has zero population and the basis states 100-0 and 100-1 are in an equal superposition. In other words, ~~a~~ at the rotation angle r_1, the state

of the system has a magnitude $|\Psi\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$, such that the system has an equal probability of occupying either energy level 100-0 or 100-1. After some further evolution r_2, the state of the system becomes $|\Psi\rangle = |1\rangle$, and the system is entirely in the 100-1 state. At this point r_2, the quantum NOT logic can be confirmed by noticing that the evolution has flipped the state of the system Thus, having δ at the above value is useful for some embodiments. Persons of skill in the art would recognize that the value of detuning can be controlled to achieve an arbitrary desired evolution of the qubit.

Please replace paragraph [0095] with the following amended paragraph:

[0095] Parameter ranges useful for a system in accordance with an embodiment of the present invention include the following. The Josephson junction can have a capacitance C = 10 femto-Farads (fF), and can range in size from about 100 nano-meters (nm) to about 1800nm, respectively corresponding to the range 10 femto-Farads (fF) – 200 fF. The critical current scales with width (for constant thickness) as $I_C \propto w^2$, and [[a]] useful widths range from about 50nm to about 4000nm, for a corresponding range of critical current values of 100nA – 20 micro-Amperes (μA). The plasma frequency can range from about 1GHz to about 500GHz. In a bistable Josephson junction (*i.e.* d-wave grain boundary Josephson junctions) as the capacitance is increased, while the critical current remains the same, the plasma frequency decreases at a rate of about $\frac{1}{\sqrt{C}}$. As the width of the Josephson junction is increased, and the film thickness is held constant, the plasma frequency increases as about $\sqrt{w}$. A ratio of Josephson energy E_J to Coulomb energy E_C can be approximately 15, and a useful range is about 32 through 3, or about 1% – 33%.

Please replace paragraph [0099] with the following amended paragraph:

[0099] Another embodiment of the present invention provides a microscopic physical system 700 (FIG. 7) for performing the methods for quantum computing described in the sections above. Embodiments of the present invention include the use of microscopic

systems as qubits. System 700 includes a single molecule that includes a double well energy potential. An example of such a molecule is the well known ammonia molecule (NH_3) which has a double well energy potential for position of the nitrogen atom. See e.g., R. Feynman, *The Feynman Lectures on Physics* (Addison-Wesley, Reading, Mass., 1964), Vol. 3, which is hereby incorporated by reference in its entirety. Other examples of such molecules are XY_3 molecules. Embodiments of the present invention make use of XY_3 molecules for quantum computing. XY_3 molecules are trigonal pyramidal molecules having hydrogen atoms (H) (or an isotope of hydrogen such as deuterium (D) or tritium (T)), all denoted by the variable Y, arranged in a plane 706. Examples of XY_3 molecules include, but are not limited to NH_2CN, ~~asine~~ arsine (AsH_3) and phosphine (PH_3). The X molecule (N in the case of ammonia, As in the case of ~~asine~~ arsine, and so forth) can be found at various points along the vertical reference line 705. System 700 can form a double well potential such as that illustrated in FIG. 1A. In some embodiments, the ground state energy level 100-0 of the double well energy potential corresponds to the X molecule being in position 701 above plane 706, and the ground state energy level 100-1 of double well energy potential corresponds to the X molecule being in position 702 below plane 706.

Please replace paragraph [00101] with the following amended paragraph:

[00101] Some embodiments of the present invention include qubits comprised of molecules with double well potential but without significant natural tunneling to perform the methods for quantum computing described in the sections above. These embodiments of the present invention can make use of XH_3 molecules having a tunneling amplitude, expressed in frequency units, that is less than the Rabi frequency. Without tunneling, a NOT operation in accordance with aspects of the present invention can be induced through Rabi oscillations. Referring to Fig. 1B, some embodiments of the present invention can make use of a third energy level 100-2 that is above the barrier 110. The level 100-2 need not be the first level above barrier 110. Some embodiments of the present invention make use of an energy level 100-2 that is about 10^{11} to about 10^{15} Hertz separated from energy levels 100-0 or 100-1. Further embodiments of the present invention include qubits comprised of ensembles of molecules having a double well potential with a tunneling amplitude that, expressed in frequency units, is approximately equal to or less than the arithmetic inverse of the decoherence time of the qubit. The dipole moment of an XY_3 molecule is non-zero and

depends on the state of the molecule. Some embodiments of the present invention use [[of]] the differing dipole moments of XY_3 molecules in an ensemble of XY_3 molecules to identify the state of the molecule. Some embodiments of the present invention use electric fields to separate molecules in each of the two ground states. In these embodiments, the electric field accelerates molecules having different dipole moments in opposite directions, causing the molecules to group into different velocities. Some embodiments of the present invention use this velocity selection to selectively induce quantum NOT operations. Laser light that is slightly detuned by an amount ε from the appropriate frequency for inducing a quantum NOT operation, *i.e.*, ω_{01}, is applied to the ensemble of molecules. The detuning ε is matched to a Doppler shift in the energy level separation of a particular velocity group. The sign of the Doppler shift is direction dependent and therefore the quantum NOT operation can be selectively preformed on the molecules of a particular velocity group. Selection of a velocity group of molecules based on Doppler shift detuning is well known. See, *e.g.*, H. J. Metcalf and P. van der Straten, *Laser Cooling and Trapping*, (Springer-Verlag, New York, 1999), and Cohen-Tannoudji *et al., Reviews of Modern Physics*, 70, p. 707 (1998), which are hereby incorporated by reference in their entireties.